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13. ABSTRACT (Maximum 200 words) Abstract: This is the final report for an AFOSR grant studying rare earth doped GaN for tunable laser sources. The report consists of a number of publications by the researchers. The work addresses the behavior of the rare earth erbium (Er) doped into GaN, with co-dopants oxygen and fluorine. The Er luminescence properties were studied versus temperature (10K, 77K, and up to room temperature), annealing treatment (number of anneals, duration, and temperature), co-dopant concentration (over three orders of magnitude), and the Er density. Co-dopants were essential to the successful detection of luminescence in the 1550 nm ($^4I_{13/2} - ^4I_{15/2}$) band. An annealing treatment following the ion implantation of the Er and co-dopant ions was also required. Photo-luminescence lifetime data versus Er density, pump wavelength, and temperature are presented. Photo-luminescence excitation (PLE) spectroscopy over the wavelength range 770-1010 nm using a tunable Ti:Sapphire laser, at 77K and room temperature, showed the usual thermal quenching for most pump wavelengths, but not all. A metal-insulator-n-type diode structure also exhibited 1550 nm luminescence. Cathodo-luminescence measurements showed weak 980 nm luminescence while the PLE measurements did not. A list of publications and presentations related to this work is also included.				
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Final Report AFOSR Contract: F49620-95-I-0301
Tunable Electronically Pumped Rare Earth Doped Nitride Lasers

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Introduction

This is the final report for an AFOSR grant. The report consists of copies of the publications that resulted from this research. There is also an appendix listing all publications and presentations that resulted from this work. The list includes publications from the previous grant, of which this was a continuation of sorts. The work addresses the behavior of the rare earth erbium (Er) ion implanted into GaN, with co-dopants oxygen and fluorine. We are pleased to acknowledge our collaborator, Dr. F. Namavar of Spire Corporation for ion implantation and characterization of the GaN material.

The Er luminescence properties were studied versus temperature (10K, 77K, and up to room temperature), annealing treatment (number of anneals, duration, and temperature), co-dopant concentration (over three orders of magnitude), and the Er density. Co-dopants were essential to the successful detection of luminescence in the 1550 nm ($^4I_{13/2}$ - $^4I_{15/2}$) band. An annealing treatment following the ion implantation of the Er and co-dopant ions was also required [Journal papers 1,3]. Photo-luminescence lifetime data versus Er density, pump wavelength, and temperature are presented [Journal paper 4].

The GaN:Er,O material was studied with photo-luminescence excitation (PLE) spectroscopy. The signal was at the peak luminescence wavelength of 1539 nm and the pump scanned over the wavelength range 770-1010 nm using a tunable Ti:Sapphire laser. Measurements were performed at 77K and at room temperature. The results showed the usual thermal quenching for most pump wavelengths, but not all [Submitted paper 1]. A GaN:Er metal-insulator-n-type (MIN) diode structure also exhibited 1550 nm luminescence [Journal paper 2].

Cathodo-luminescence measurements showed weak 980 nm luminescence while the PLE measurements did not [Journal paper 5]. A review paper of the field of rare earth doped semiconductors is currently being revised [Submitted paper 2]. A copy of the accepted paper will be sent to the AFOSR following final revisions.

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Appendix I. Publications and Presentations

This appendix lists the papers and presentations by the student funded with the AASERT grant. It also includes the AASERT student's Ph.D. thesis title and some recent works submitted to journals.

Journal Papers

1. J.T. Torvik, C.H. Qiu, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Photo-, cathodo-, and electro-luminescence from erbium and oxygen co-implanted GaN," J. Appl. Phys. (May 1997).
2. J.T. Torvik, R.J. Feuerstein, J.I. Pankove, C.H. Qiu, F. Namavar, "Electro-luminescence from erbium and oxygen coimplanted GaN," Appl. Phys. Lett., **69**(14), pp. 2098-2100 (1996).
3. C.H. Qiu, M.W. Leksono, J. Torvik, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Cathodo-luminescence study of Er and Oxygen co-implanted Gallium Nitride thin films on Sapphire substrates," Appl. Phys. Lett. **66**(5), pp. 564 (1995).

Conference Papers

1. J.T. Torvik, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Annealing study of erbium and oxygen implanted gallium nitride," Mat'ls Res. Soc. Symp. Vol. **422**, pp. 199-204, MRS Pittsburgh, PA (1996). Ed.'s S. Coffa, A. Polman, R.N. Schwartz.
2. J.T. Torvik, C.H. Qiu, R.J. Feuerstein, J.I. Pankove, F. Namavar, "Luminescence at 1539 nm from Er and Oxygen implanted GaN." 1996 Conf. on Optoelectronic and Microelectronic Materials and Devices (COMMAD 96), Dec 9-11, 1996, Canberra, Australia.

Ph.D. Dissertation

Dr. John T. Torvik, "The Doping and Characterization of Erbium in Gallium Nitride."

Submitted Works

1. J.T. Torvik, R.J. Feuerstein, C.H. Qiu, J.I. Pankove, F. Namavar, Photoluminescence excitation measurements on erbium implanted GaN," Submitted to J. Appl. Phys. April 1997.
2. J.T. Torvik, R.J. Feuerstein, W.A. Melton, J.I. Pankove, "Luminescence in Rare Earth Doped Semiconductors," Applied Physics Reviews, (currently incorporating reviewers comments).

Conference, Workshop and Other Presentations

(by R.J. Feuerstein)

1. "Rare Earth doped semiconductors for interconnects," at the ISHM/IEPS Advanced Technology Workshop on Optoelectronics, Ojai, CA, invited paper, Feb. 21, 1995.
2. "Luminescence in Rare Earth Doped Semiconductors," Paper to URSI meeting, Boulder, CO, invited paper, Paper D1-3, Jan. 3, 1995.
3. "Cathodoluminescence in Erbium doped Gallium Nitride," at the European Quantum Electr. Conf., Amsterdam, Netherlands, August 28 - Sept. 2, 1994.
4. "Luminescence in Er doped GaN," at the Rare Earth Doped Optoelectronic Materials Workshop, Hughes Laboratories, Malibu, CA, June 16-17, 1994 .
5. "Erbium Doped Silicon for Optical Sources and Amplifiers," at the URSI meeting, Boulder, CO., Jan. 1994.
6. "Luminescence in Rare Earth Doped Semiconductors," at the National Institute of Standards and Technology, Boulder, CO., Nov. 12, 1993.
7. "Erbium Doped Silicon for Lasers and Amplifiers," to the Microwave Optics Seminar, Univ. of CO, Boulder, CO, March 2, 1993.

Submitted Works

1. J.T. Torvik, R.J. Feuerstein, C.H. Qiu, J.I. Pankove, F. Namavar, Photoluminescence excitation measurements on erbium implanted GaN," Submitted to J. Appl. Phys. April 1997.
2. J.T. Torvik, R.J. Feuerstein, W.A. Melton, J.I. Pankove, "Luminescence in Rare Earth Doped Semiconductors," Applied Physics Reviews, (currently implementing reviewers comments).